

TELEDYNE'S MULTI-USER SYSTEM FOR EARTH SENSING (MUSES)

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Ray Perkins¹, David Krutz², Rupert Mueller², Emiliano Carmona², Robert Griffin³, Lewis Graham⁴, Randy Miller¹

¹ Teledyne Brown Engineering, ² DLR, ³ ARSC, ⁴ GeoCue Group

Parent Company Teledyne Technologies



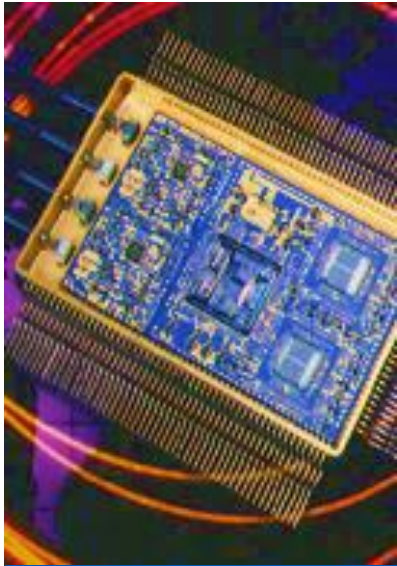
Everywhere you look™

- ▶ Headquartered in Thousand Oaks, California with locations across the globe
- ▶ \$2.3B in 2015 revenues; over 9,300 employees
- ▶ Teledyne Technologies is a leading provider of sophisticated instrumentation, digital imaging products and software, aerospace and defense electronics, and engineered systems. For more information, visit Teledyne Technologies' website at www.teledyne.com.



Teledyne Technologies

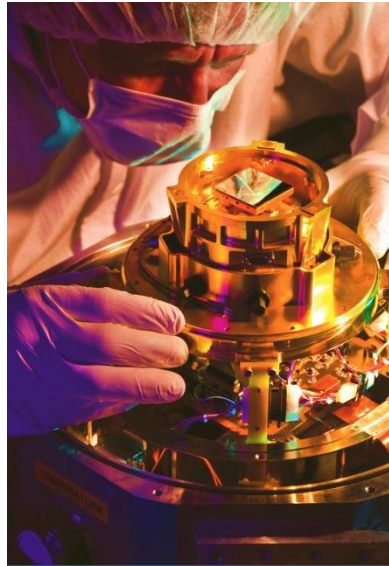
Four Segments – \$2.3B 2015



**Aerospace and
Defense
Electronics**



Instrumentation



Digital Imaging

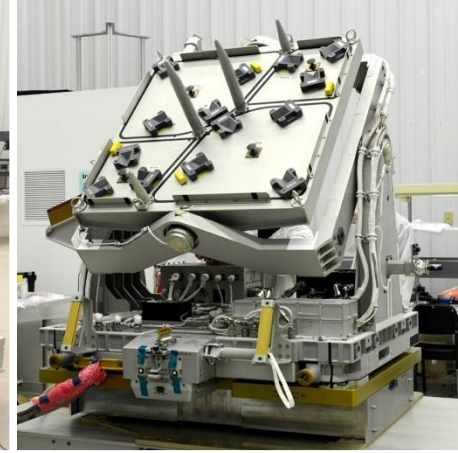


**Engineered
Systems**



Multi-User System for Earth Sensing (MUSES)

- ▶ MUSES Platform
- ▶ Located on ELC 4
- ▶ Inertially stabilized
- ▶ Precise pointing and Earth surface target tracking
- ▶ Up to 4 robotically installed instruments
- ▶ Total data downlink ~225 GB/day
- ▶ Teledyne owns the platform, determines pointing schedules, and retains data rights in cooperation with partners
- ▶ Instruments launched in “soft stowage”



Earth Observation From the ISS – Why It Works

- ▶ Coverage of ~90% of populated Earth
- ▶ Coverage of ~100% of ocean shipping lanes and major navigational ports
- ▶ Coverage of 100% of tropics and equatorial region
- ▶ 3-5 day average cadence
- ▶ Sophisticated spacecraft bus with required resources
- ▶ Upgrade and exchange of instruments as technology and/or markets evolve
- ▶ Traditional barriers to entry minimized



Why the ISS Works for Teledyne

- ▶ **60 years of corporate experience working NASA programs from Explorer 1 to the new Space Launch System**
- ▶ **Extensive experience with ISS payloads**
 - Designed and manufactured ISS systems and hardware (Environmental Controls and Life Support Systems, Logistics Carriers, Flight Releasable Attachment Mechanisms)
 - Designed and built payload hardware (Microgravity Science Glovebox, Microgravity Science Research Rack)
 - Prime contractor for the Payload Operations and Integration Center at Marshall Space Flight Center
- ▶ **Rich corporate history in design and development of sensors (Hubble and James Web Space Telescopes, Mars Science Laboratory - Curiosity)**



Teledyne MUSES Commercial Products

► Turn-Key Instrument Missions

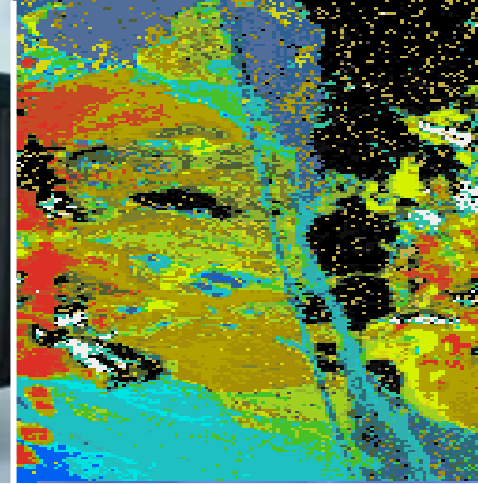
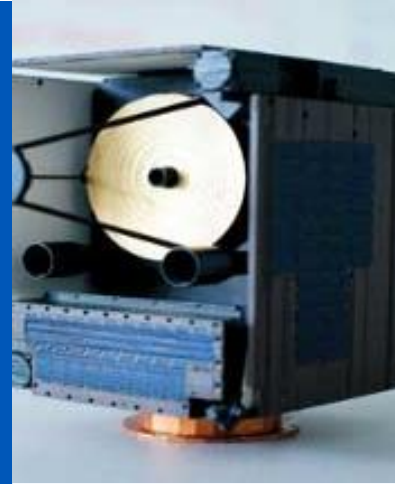
- Development, integration, and operations.
- Negotiable Template: 30-month engagement; 18-month integration, 12-month flight on MUSES (6 month for primary)
- TRL maturation, prove-out of instrument design, early data products prior to free-flyer missions.

► Commercial Data Sales

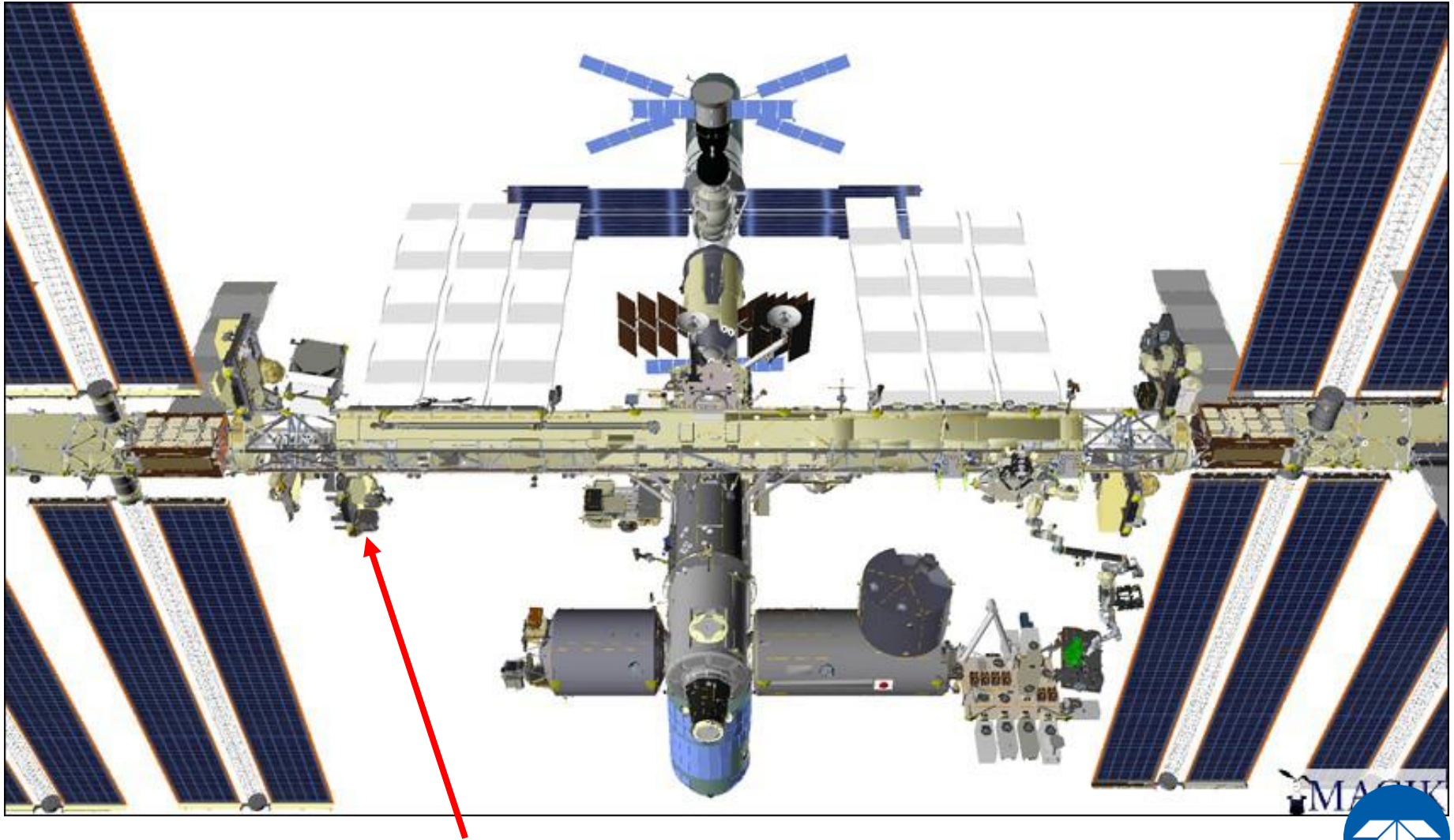
- Archive, tasking, subscription
- From one image to the whole data pipeline
- Non-exclusive, limited exclusivity, exclusivity options

► Analytics and Decision Information Products

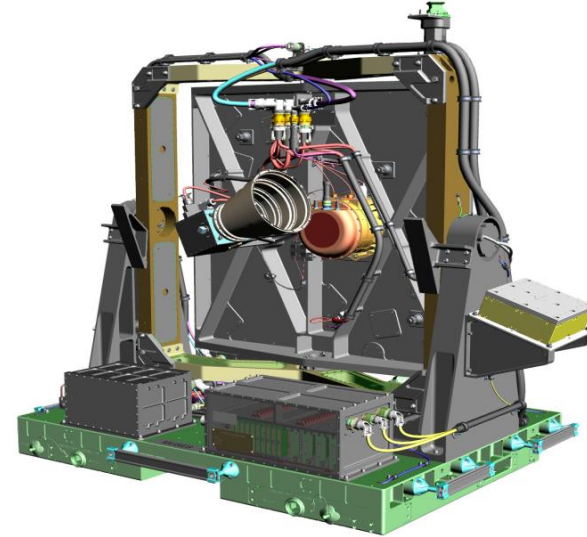
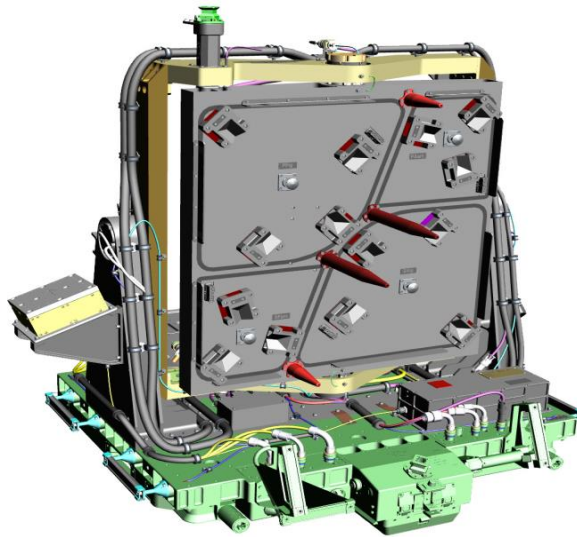
- Commercial, scientific, humanitarian value
- Collaborative Research and Development
- Partnership and mutually-beneficial capacity building, to address new markets and new opportunities



MUSES Location on ELC-4



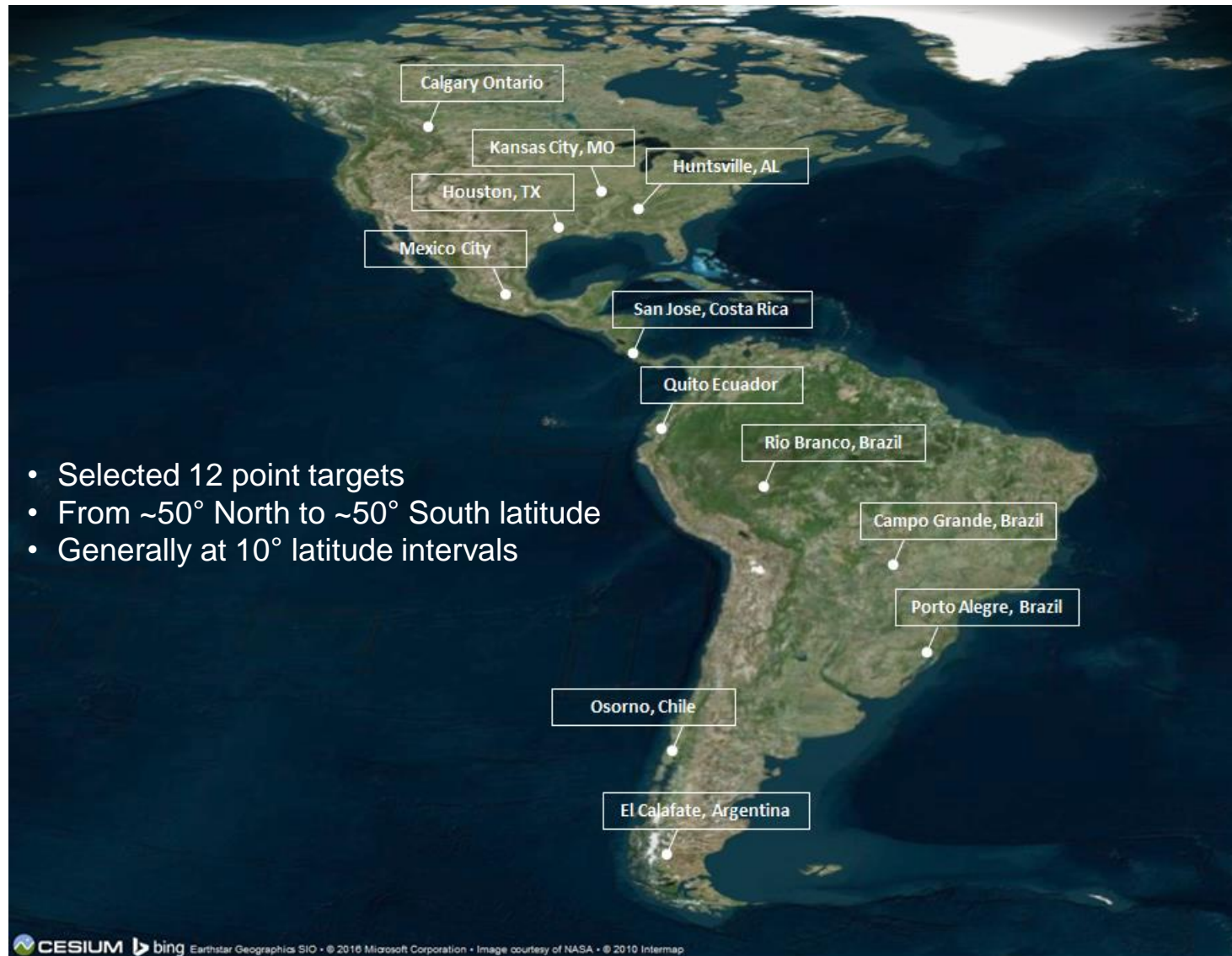
Platform Capabilities



Pointing Knowledge	≤ 30 arc seconds (~ 60 m on ground from 400 km altitude)
Field of Regard	5° outboard cross-track 45° inboard cross-track +/- 25° along-track
Star Tracker	Sodern SED26
Inertial Measurement Unit	Honeywell Miniature Inertial Measurement Unit (MIMU)
Precision Time	Sourced from the ISS GPS, ± 250 usec to MUSES instruments
Location knowledge	Sourced from the ISS GPS, ± 50 meters, RMS
Orbit	51.6° Inclination, 400 km altitude $\pm 5\%$ (nominal)
Data Processing	Linux Server on-board ISS with redundant 8 TB storage
Daily Downlink Capacity	225 GB

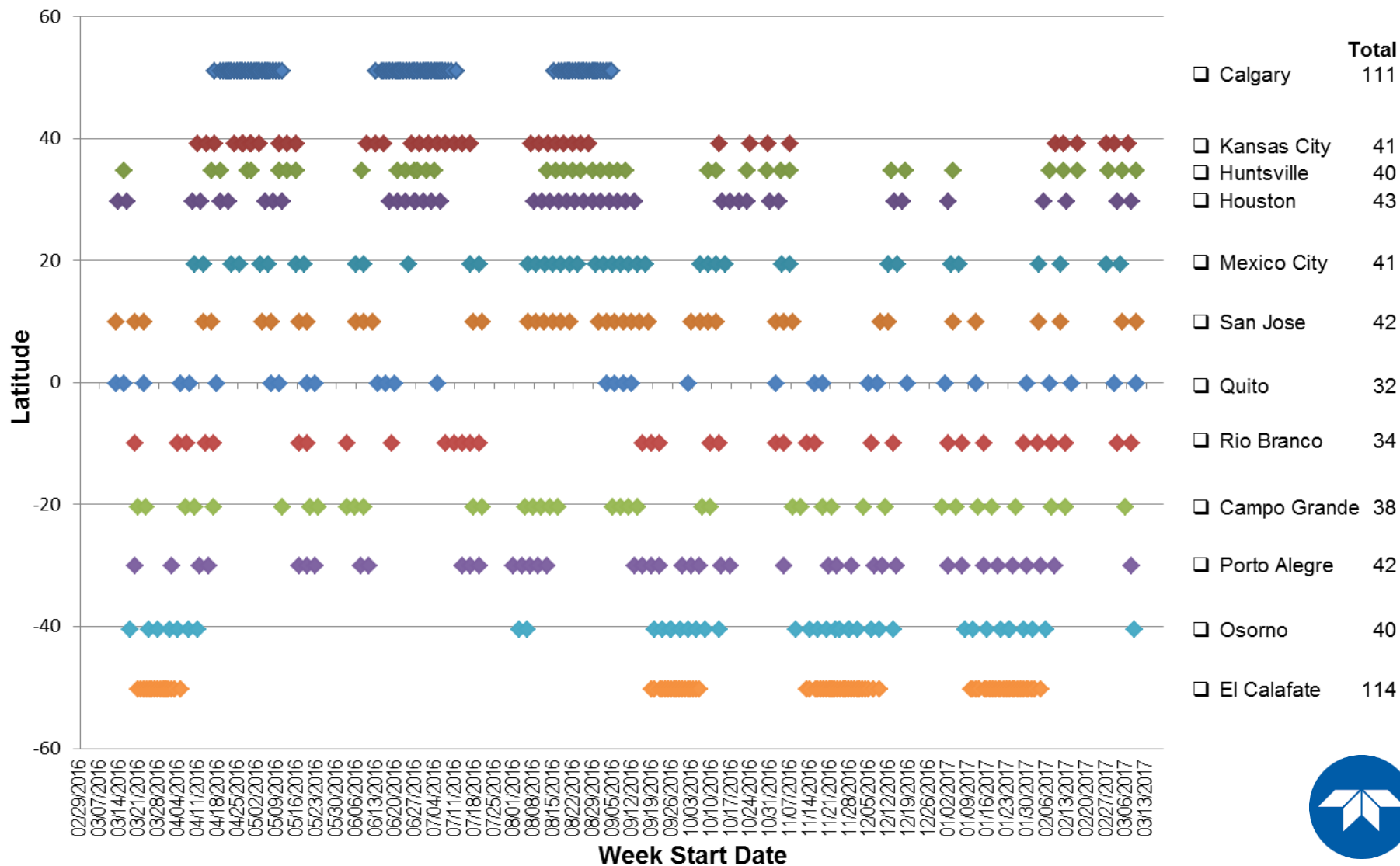


MUSES Imaging Opportunity Analysis



MUSES Imaging Opportunities: $\geq 30^\circ$ Solar Elevation

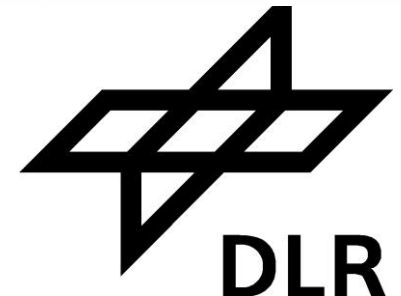
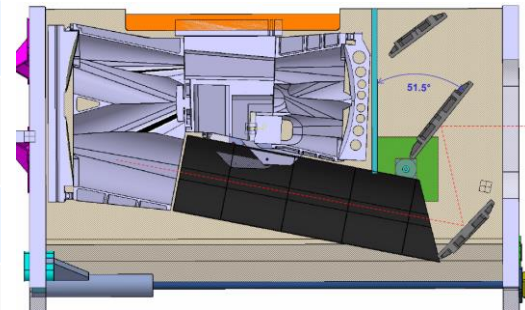
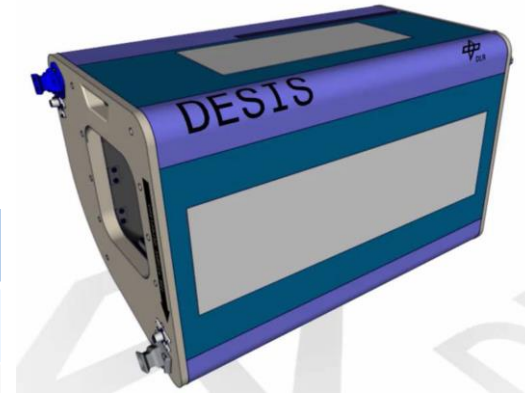
Annual MUSES Imaging Opportunities
 Solar Elevation $\geq 30^\circ$, Off Nadir $\leq 25^\circ$



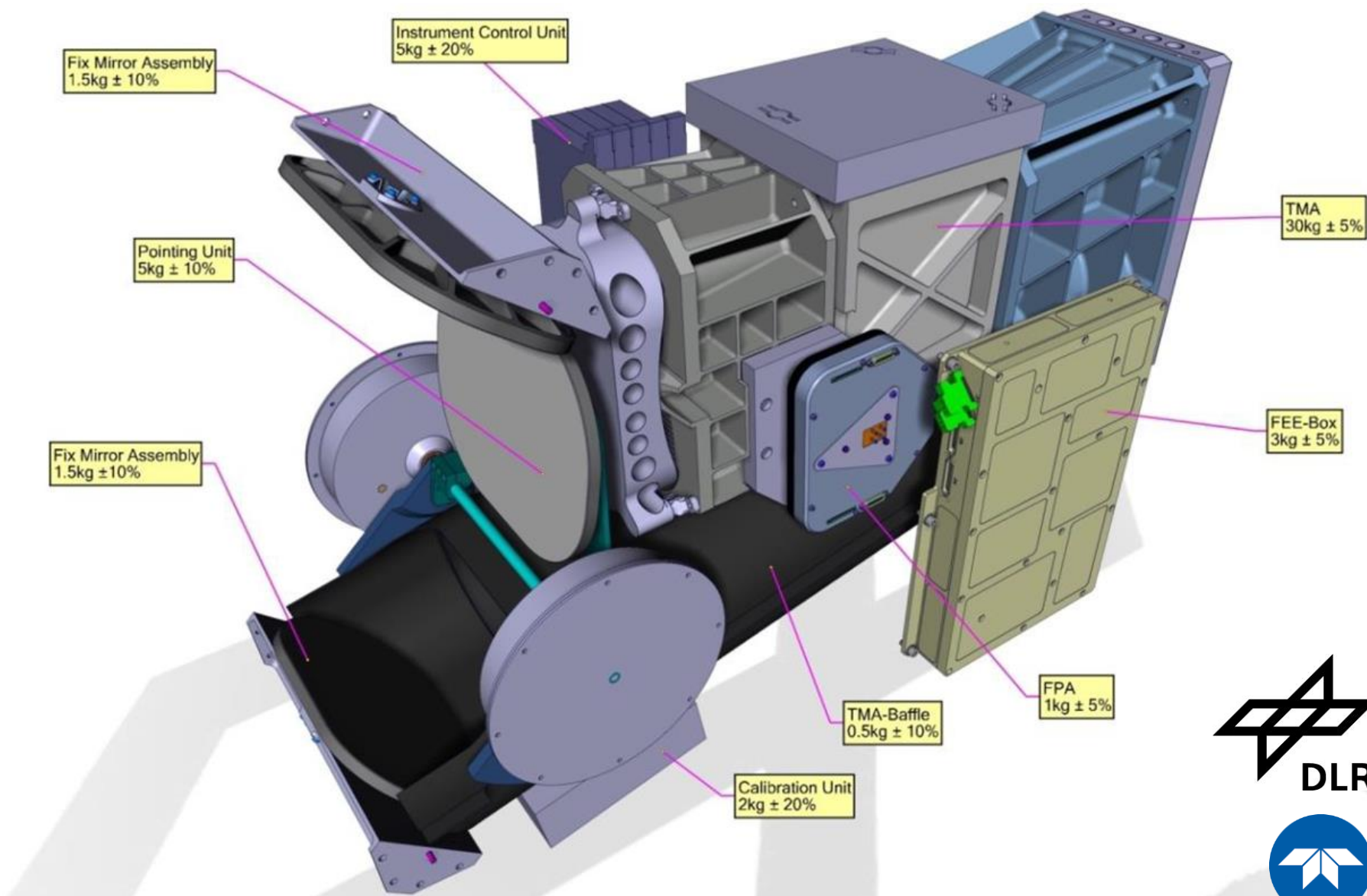
DLR Earth Sensing Imaging Spectrometer (DESI-30)

- ▶ Teledyne & DLR, the German Space Centre, have partnered for a visible to near-IR imaging spectrometer for MUSES

Characteristic	DESI-30 Features
Ground Sampling Distance	30 m @ 400 km altitude
Ground Swath	30 km @ 400 km altitude
Spectral Range	400 nm – 1000 nm
Spectral Bins	Measured: 235 @ 2.55 nm Programmable binning on-orbit
Quantization	12 bits
Signal to Noise Ratio @ 550 nm	205:1 sampled at 2.55 nm 406:1 binned to 10.2 nm
On-board calibration	Dark Field for DSNU LED Array for PRNU
Independent Pointing	Pointing Unit $\pm 15^\circ$ Along Track
Independent Time and Location	On-board GPS



DESIS Internal Design

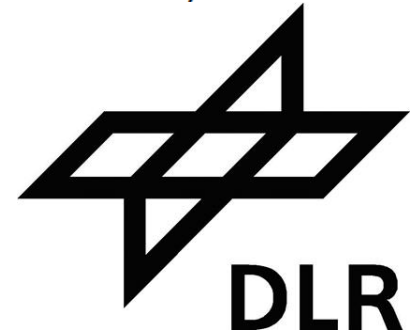
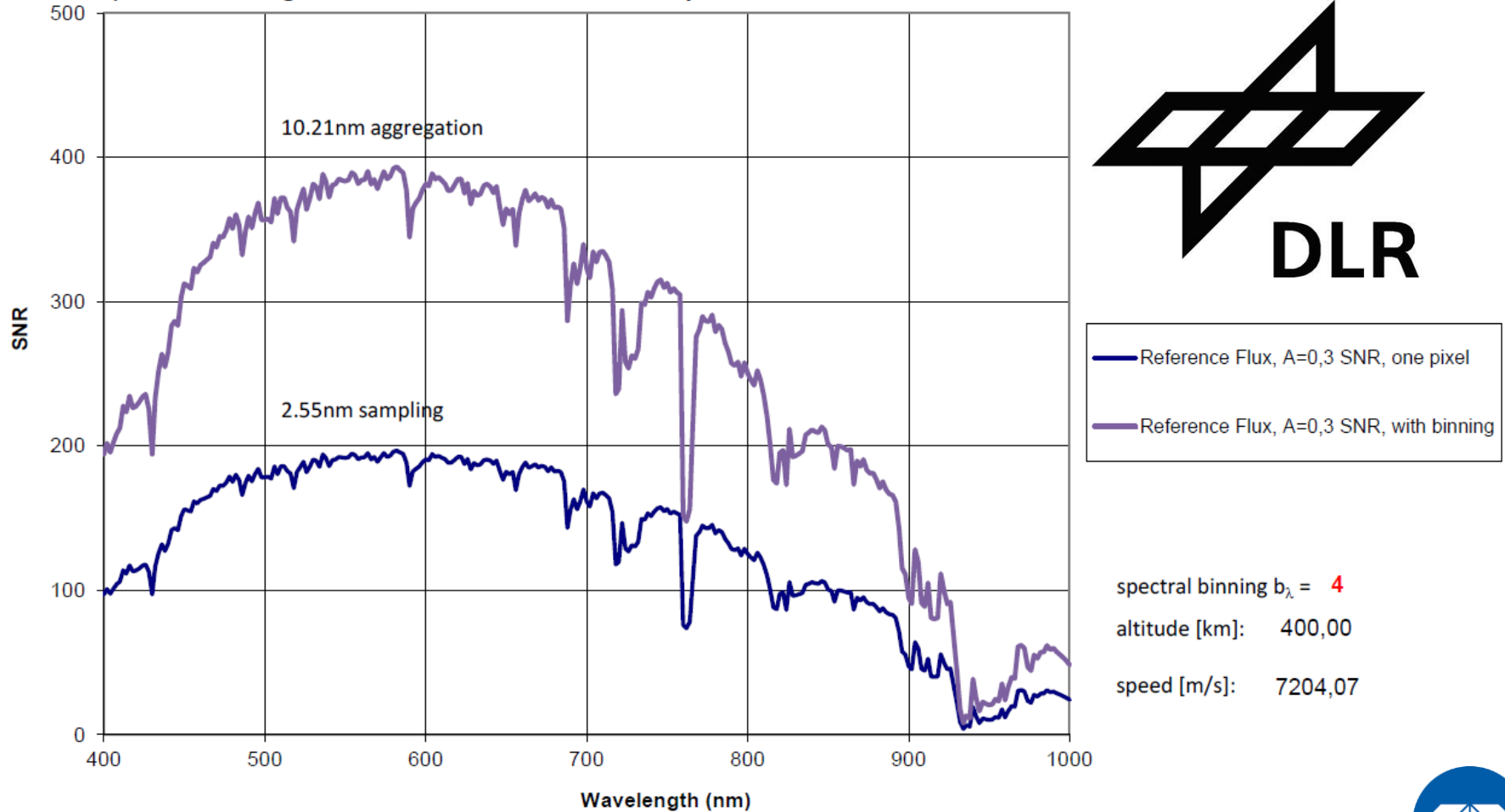


DESIS Signal to Noise (SNR)

DLR/BA/OS Schwarzer

10.06.2015

DESIS : Offner with TMA, Ag mirror, CIS2001 (BAE), trapeze grating: SNR
(sun zenith angle 45°, Modtran: Standard atmosphere mid latitude summer, $\Delta\lambda = 2\text{nm} / \text{H. Witt}$)



SNR for 2.55 nm sampling distance and spectral binning by factor 4



Current MUSES/DESI Status

► MUSES

- Final closeout of pre-launch verifications
- Performing ground testing and performance characterizations
- Manifested for launch on SpaceX-11
- Expect SpaceX-11 launch by Q1, 2017





► DESIS

- Critical Design Review in Berlin in May 2016
- Planned launch in Q2, 2017

► Commission MUSES and DESIS during Q2 2017



Major Agreements, Partnerships, and Teaming

Name	Type	Summary
	Enabling, Science	<ul style="list-style-type: none"> Cooperative Agreement (NNJ12GA21A) with the ISS Program Office for MUSES \$15 M data purchase agreement
	Enabling, Science, Humanitarian	<p>Implementing agreement for the DLR Earth Sensing Imaging Spectrometer (DESI)</p> <ul style="list-style-type: none"> Covers the design, development, and operation of the DESIS instrument Provision of imagery to DLR for scientific and humanitarian purposes Bi-lateral cooperation and sharing of all DESIS calibration data TBE licensing of DESIS image processing algorithms and software
	Science	<p>Alabama Remote Sensing Consortium (ARSC)</p> <ul style="list-style-type: none"> UA Huntsville, Alabama A&M University, Auburn University Provision of imagery for research & instruction ARSC will support periodic vicarious calibration activities
	Commercial	<ul style="list-style-type: none"> Cloud-based image process and archive



Subsequent Presentations



Janja Avbelj, PhD

DLR Remote Sensing Technology Institute

“Image products from the new hyperspectral sensor DESIS”



Lewis Graham

GeoCue Group

“Building High Performance Processing Systems in Amazon Web Services”

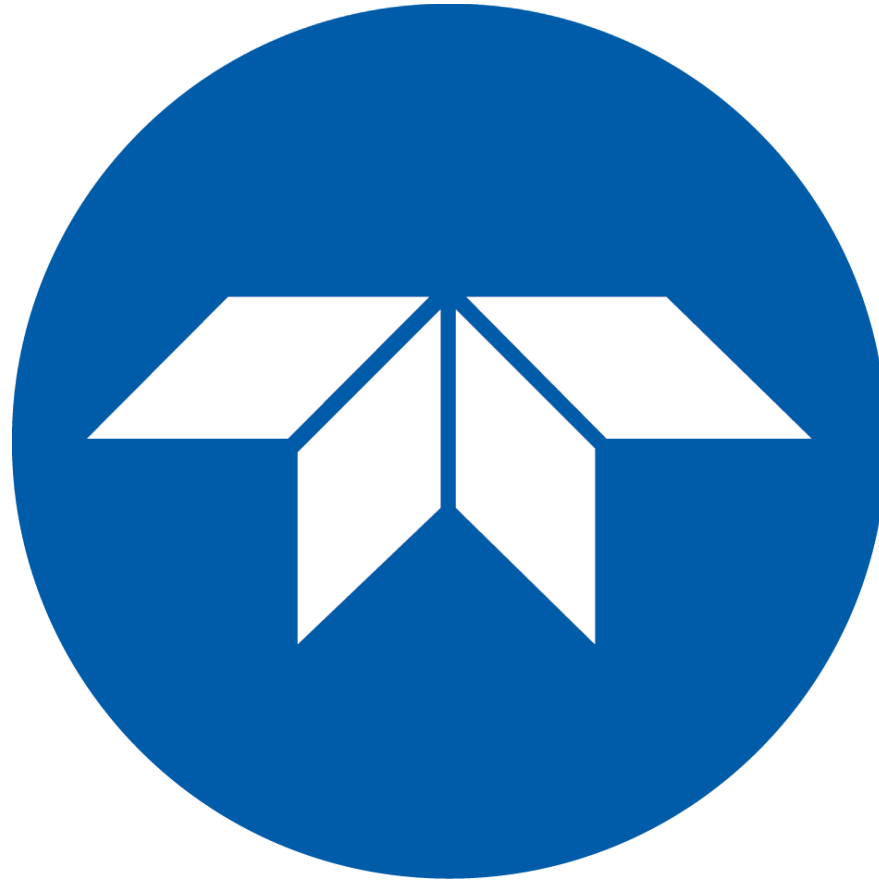


Ray Perkins

Teledyne Brown Engineering

“Imaging Spectroscopy Applications Using the DESIS Hyperspectral Instrument on MUSES”





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